

# The Lorentz and CPT violating effects on the charged Higgs boson decays $H^+ \rightarrow W^+ H^0(h^0, A^0)$

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## Abstract

We study the decay widths of the processes  $H^+ \rightarrow W^+ H^0(h^0, A^0)$ , including the Lorentz violating effects and analyze the possible CPT violating asymmetry arising from CPT odd coefficients. We observe that these effects are too small to be detected, since the corresponding coefficients are highly suppressed at the low energy scale.

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# 1 Introduction

The discovery of charged Higgs boson is an effective signal about the existence of the multi Higgs doublet structure which is lying beyond the standard model (SM), such as two Higgs doublet model (2HDM), minimal extension of the standard model (MSSM). There is an extensive work on the charged Higgs boson and its possible decays in the literature.

The charged Higgs production has been studied in several theoretical and experimental works [1, 2, 3, 4]. A search for pair-produced charged Higgs bosons was analyzed with the L3 detector at LEP and its mass was obtained as  $m_{H^+} > 76.5 (GeV)$  [2]. The CDF and D0 collaborations have studied  $H^+$  bosons at tevatron, in the case of  $p\bar{p} \rightarrow t\bar{t}$ , with at least one of the top quark decaying via  $t \rightarrow H^+b$  and they present the charged Higgs mass lower limits as  $m_{H^+} > 77.4 (GeV)$  [3]. In the recent work [4], a search for pair produced charged Higgs boson is performed using the data from the DELPHI detector at LEP II and the existence of this particle with mass lower than  $76.7 (74.4) GeV$  in the type I (II) 2HDM is excluded.

The charged Higgs boson decays received a considerable interest. In [5, 6] it was shown that the dominate decay modes of the charged Higgs boson were  $H^+ \rightarrow \tau^+\nu$  and  $H^+ \rightarrow t\bar{b}$ .  $H^+ \rightarrow t\bar{b}$  process in the minimal supersymmetric model (MSSM) has been analyzed in [7]. Another process which was a candidate for large branching ratio (BR) is  $H^+ \rightarrow W^+h^0$  decay and it was examined in [8]. [9] is devoted to the analysis of  $H^+ \rightarrow W^+\gamma$ ,  $H^+ \rightarrow W^+Z$  and  $H^+ \rightarrow W^+h^0$  decays in the framework of the effective lagrangian extension of the 2HDM. In this work the BRs have been obtained at the order of magnitude of  $10^{-5}$ ,  $10^{-1}$  and  $O(1)$ , respectively.  $H^+ \rightarrow W^+h^0$  decay has been studied in MSSM in [10]. [11] is devoted to the analysis of  $H^+ \rightarrow W^+A^0$  decay in the framework of the 2HDM and, in this work, it was concluded that this channel might be dominant one over a wide range of parameter space relevant at present and future colliders. The decays of the charged Higgs boson, including the radiative modes into decays  $W^+\gamma$  and  $W^+Z$ , has been studied mostly in the framework of the 2HDM and MSSM in [12].

In the present work, we study the Lorentz and CPT violating effects on the decay width ( $\Gamma$ ) of the processes  $H^+ \rightarrow H^0 W^+ (h^0 W^+, A^0 W^+)$  where  $H^0$ ,  $h^0$  ( $A^0$ ) are the scalar (pseudo scalar) Higgs fields in the model III version of the 2HDM. A Lorentz invariant underlying fundamental theory brings new Lorentz and CPT violating interactions in the model III with the possible spontaneous breaking mechanism. The extended theories like the string theory [13], the non-commutative theories [14], exist at higher scales where the Lorentz and CPT symmetries are broken [15]. The space-time-varying scalar couplings can also lead to Lorentz violating effects

described by the SM extensions [16]. The Lorentz violation ensures tiny interactions at the low energy level and they are presented in the SM extension in [17, 19].

In the literature there are various studies on the general Lorentz and CPT violating effects in the framework of Quantum Electro Dynamics (QED), the noncommutative space time, the Wess-Zumino model and on the restriction of the Lorentz violating coefficients coming from the experiments [20, 21]. Furthermore, some phenomenological works have been done on the the Lorentz and CPT violating effects in the SM and the model III extensions [22] and it was observed that these tiny effects are far from the detection in the experiments. [23] is devoted to the bounds on the CPT-even asymmetric (symmetric ) coefficients which arise from the one-loop contributions to the photon propagator (from the equivalent  $c_{\mu\nu}$  coefficients in the fermion sector), and those from the CPT-odd coefficient which arise from bounds on the vacuum expectation value of the Z-boson.

The present work is devoted to the prediction of Lorentz and CPT violating effects on the decay widths of the charged Higgs  $H^+$  decays into  $W^+$  boson and scalar (pseudo scalar) Higgs bosons, in the model III version of 2HDM. We study the relative behavior of the Lorentz violating effects which are carried by tiny CPT even and CPT odd coefficients and estimate the possible CPT violating asymmetry arising from CPT odd one. We observe that these additional effects are too weak to be detected in the present experiments, since the coefficients driving those effects lie in the range which is regulated by the suppression scale taken as the ratio of the light one, of the order of the electroweak scale, to the one of the order of the Planck mass [21].

The paper is organized as follows: In Section 2, we present the theoretical expression of the decay width  $\Gamma$ , for the  $H^+ \rightarrow H^0 W^+$  ( $h^0 W^+$ ,  $A^0 W^+$ ) decays, with the inclusion of the Lorentz and CPT violating effects. Section 3 is devoted to discussion and our conclusions.

## 2 The Lorentz and CPT violating effects on charged Higgs decays into $W^+ S$ ( $S = H^0, h^0, A^0$ ).

This section is devoted to the Lorentz and CPT violating effects on the  $\Gamma$  of the charged Higgs decays,  $H^+ \rightarrow H^0 W^+$  ( $h^0 W^+$ ,  $A^0 W^+$ ) where  $H^0, h^0$  ( $A^0$ ) are the scalar, (pseudo scalar) Higgs fields in the 2HDM (see [24] for review)). The charged Higgs decays under consideration exist in the tree level and the Lorentz violating effects appear with the addition new interactions which may come from more fundamental theory in the Planck scale. These tiny effects are regulated by the new coefficients, having small numerical values which has the suppression

scale proportional to the ratio of the mass in the electroweak scale to the one in the Planck scale.

The charged Higgs decays,  $H^+ \rightarrow H^0 W^+ (h^0 W^+, A^0 W^+)$  are induced by the so called kinetic part of the lagrangian and, in the 2HDM, it reads

$$\mathcal{L}_{Higgs} = (D_\mu \phi_1)^\dagger D_\mu \phi_1 + (D_\mu \phi_2)^\dagger D_\mu \phi_2, \quad (1)$$

where  $\phi_{1,2}$  are the Higgs scalar doublets in a suitable basis (see [25] for example)

$$\phi_1 = \frac{1}{\sqrt{2}} \left[ \begin{pmatrix} 0 \\ v + \bar{H}^0 \end{pmatrix} + \begin{pmatrix} \sqrt{2}\chi^+ \\ i\chi^0 \end{pmatrix} \right]; \phi_2 = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2}H^+ \\ H_1 + iH_2 \end{pmatrix}, \quad (2)$$

with the vacuum expectation values

$$\langle \phi_1 \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}; \langle \phi_2 \rangle = 0. \quad (3)$$

Here the neutral bosons  $\bar{H}_0$ ,  $H_1$  and  $H_2$  are defined in terms of the mass eigenstates  $H_0$ ,  $h_0$  and  $A_0$  as

$$\begin{aligned} \bar{H}_0 &= (H_0 \cos \alpha - h_0 \sin \alpha), \\ H_1 &= (h_0 \cos \alpha + H_0 \sin \alpha), \\ H_2 &= A_0, \end{aligned} \quad (4)$$

where  $\alpha$  is the mixing angle and  $v$  is proportional to the vacuum expectation value of the doublet  $\phi_1$  (eq. (3)). In eq. (1)  $D_\mu$  is the covariant derivative,  $D_\mu = \partial_\mu + \frac{ig}{2}\tau \cdot W_\mu + \frac{ig'}{2}Y B_\mu$ ,  $\tau$  is the Pauli spin matrix,  $Y$  is the weak hypercharge,  $B_\mu$  ( $W_\mu$ ) is the  $U(1)_Y$  ( $SU(2)_L$  triplet) gauge field.

The additional part due to the Lorentz violating effects can be represented by the CPT-even and CPT-odd lagrangian [17] as

$$\begin{aligned} \mathcal{L}_{Higgs\,LorVio}^{CPT-even} &= \frac{1}{2} (k_{\phi\phi})^{\mu\nu} \left( (D_\mu \phi_1)^\dagger D_\nu \phi_1 + (D_\mu \phi_2)^\dagger D_\nu \phi_2 \right) + h.c. \\ &- \frac{1}{2} (k_{\phi W})^{\mu\nu} (\phi_1^\dagger W_{\mu\nu} \phi_1 + \phi_2^\dagger W_{\mu\nu} \phi_2), \\ \mathcal{L}_{Higgs\,LorVio}^{CPT-odd} &= i(k_\phi)^\mu (\phi_1^\dagger D_\mu \phi_1 + \phi_2^\dagger D_\mu \phi_2) + h.c., \end{aligned} \quad (5)$$

where the coefficients  $k_{\phi\phi}$  ( $k_{\phi W}$ ) are dimensionless with symmetric real and antisymmetric imaginary parts (has dimension of mass and real antisymmetric). The CPT odd coefficient  $k_\phi$  is a complex number and has dimension of mass. Here  $W_{\mu\nu}$  is the field tensor which is defined in terms of the gauge field  $W_\mu$ ,

$$W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu + ig[W_\mu, W_\nu]. \quad (6)$$

This Lagrangian brings new Lorentz violating corrections driven by the vertices

$$\begin{aligned}(V^{even})^\mu &= \frac{1}{2} g (k_{\phi\phi}^{Sym})^{\mu\nu} (k-p)_\nu + i (k_{\phi W})^{\mu\nu} q_\nu, \\ (V^{odd})^\mu &= \frac{1}{2} g (k_\phi^\mu + k_\phi^{\mu+}).\end{aligned}\tag{7}$$

where  $p(k; q)$  is the four momentum vector of incoming  $H^+$  ( $S = H^0, h^0, A^0; W^+$ ),  $\sin\alpha (V^{even})^\mu$  ( $\cos\alpha (V^{even})^\mu, -i (V^{even})^\mu$ ) is the CPT-even Lorentz violating vertex and  $\sin\alpha V^{\mu odd}$  ( $\cos\alpha V^{\mu odd}, (-i) V^{\mu odd}$ ) is the CPT-odd Lorentz violating vertex for the  $H^+ \rightarrow H^0 (h^0, A^0) W^+$  decay.

It is well known that the invariant phase-space elements in the presence of Lorentz violation are modified [18]. In the case that there are no Lorentz violating effects, the expression for decay width in the  $H^+$  boson rest frame reads

$$\begin{aligned}d\Gamma &= \frac{(2\pi)^4}{2 m_{H^+}} \delta^{(4)}(p_{H^+} - q_W - q_S) \frac{d^3 q_W}{(2\pi)^3 2 E_W} \frac{d^3 q_S}{(2\pi)^3 2 E_S} \\ &\times |M|^2(p_{H^+}, q_W, q_S)\end{aligned}\tag{8}$$

with the four momentum vector of  $H^+$  boson ( $W^+, S$ )  $p_{H^+}$  ( $q_W, q_S$ ), and the matrix element  $M$  for the process  $H^+ \rightarrow S W^+$ . With the inclusion of the new Lorentz violating parameters in the neutral Higgs sector, the  $S$  boson dispersion relation changes and this induces an additional part in the phase space element  $\frac{d^3 q_S}{(2\pi)^3 2 E_S}$ .

The variational procedure generates the equation (see eqs. (1) and (5))

$$(-\partial^2 - m_S^2 - \text{Re}[k_{\phi\phi}^{\mu\nu}] \partial_\mu \partial_\nu - 2 \text{Im}[k_\phi^\mu] \partial_\mu) S = 0,\tag{9}$$

which leads to the dispersion relation

$$(q_S^2 (1 + |k_{\phi\phi}^{Sym}|) - m_S^2)^2 + 4 (\text{Im}[k_\phi^\mu] q_{S\mu})^2 = 0.\tag{10}$$

Here take the special parametrization where the symmetric part of the coefficient  $k_{\phi\phi}^{\mu\nu}$  is proportional to the identity:

$$k_{\phi\phi}^{\mu\nu} = \delta^{\mu\nu} |k_{\phi\phi}^{Sym}| + k_{\phi\phi}^{ASym\mu\nu}.\tag{11}$$

and, in the following, we assume that  $k_\phi^\mu$  is real. Finally the dispersion relation becomes

$$q_S^2 (1 + |k_{\phi\phi}^{Sym}|) - m_S^2 = 0,\tag{12}$$

and the energy eigenvalues are obtained as

$$E_S^\pm = \pm \sqrt{\frac{m_S^2 + (1 + |k_{\phi\phi}^{Sym}|) \vec{q}_S^2}{(1 + |k_{\phi\phi}^{Sym}|)}}.$$

Using the vertices presented eq. (7) and the modified phase space element, the decay width  $\Gamma$  in the  $H^\pm$  boson rest frame, linear in the Lorentz violating parameters, is obtained as

$$\Gamma^S = \frac{1}{64 \pi m_{H^\pm}^3} g^2 \sqrt{\Delta} (\Gamma_0^S + \Gamma_{LorVio}^S) \quad (13)$$

where

$$\begin{aligned} \Gamma_0^S &= \frac{1}{m_W^2} f_1^S \xi, \\ \Gamma_{LorVio}^S &= \frac{1}{m_W^2 m_{H^\pm}} \xi \left( -2 \text{Re}[k_\phi^0] f_1^S + \frac{1}{m_{H^\pm}} k_{\phi\phi}^{Sym} f_2^S \left( 1 + \frac{m_S^2 m_{H^\pm}^2}{\Delta} \right) \right) \end{aligned} \quad (14)$$

with

$$\begin{aligned} \Delta &= (m_S^2 + m_{H^\pm}^2 - m_W^2)^2 - 4 m_S^2 m_{H^\pm}^2, \\ f_1^S &= \beta \left( m_S^4 + (m_{H^\pm}^2 - m_W^2)^2 - 2 m_S^2 (m_{H^\pm}^2 + m_W^2) \right), \\ f_2^S &= \beta \left( -m_S^6 + 3 m_S^4 (m_{H^\pm}^2 + m_W^2) + (m_{H^\pm}^2 - m_W^2)^2 (m_{H^\pm}^2 + m_W^2) \right. \\ &\quad \left. - m_S^2 (3 m_{H^\pm}^4 + 2 m_{H^\pm}^2 m_W^2 + 3 m_W^4) \right) \end{aligned} \quad (15)$$

Here the parameters  $\xi$  and  $\beta$  read  $\xi = \sin^2 \alpha (\cos^2 \alpha, 1)$  for  $S = H^0 (h^0, A^0)$  and  $\beta = 1 (-1)$  for  $S = H^\pm, h^\pm (A^\pm)$ . Notice that the additional term  $\frac{m_S^2 m_{H^\pm}^2}{\Delta}$  in the parenthesis, in eq. (14), is due to the modified phase factor.

Eq. (14) shows that the Lorentz violating effects enter into decay width of charged Higgs boson with the CPT even  $k_{\phi\phi}^{Sym}$  and CPT odd  $k_\phi$  coefficients. The latter one is responsible for the tiny CPT asymmetry in these decays, namely

$$A_{CPT} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}, \quad (16)$$

where  $\bar{\Gamma}$  the CPT conjugate of the  $\Gamma$ .

### 3 Discussion

The SM model is invariant under Lorentz and CPT transformations. However, the spontaneous Lorentz violation in the Lorentz and CPT invariant more fundamental theory at the Planck scale brings new interactions in the lower level where the ordinary SM lies. These additional interactions are naturally suppressed and their strengths are proportional to the ratio of the light mass at the order of  $m_{f,W,Z}$  to the one of the order of the Planck mass. This leads to a

range  $10^{-23} - 10^{-17}$  [21] for the coefficients which carry the Lorentz and CPT violating effects. Notice that the first (second) number represent the electron mass  $m_e$  ( $m_{EW} \sim 250 \text{ GeV}$ ) scale.

In this section, we study the Lorentz and CPT violating effects on the decay widths of the charged Higgs  $H^+$  decays  $H^+ \rightarrow H^0(h^0, A^0)$  and predict a possible CPT violating asymmetry arising from CPT odd coefficients. The Lorentz violation is regulated by CPT even  $k_{\phi\phi}^{Sym}$ ,  $k_{\phi W}$  and CPT odd  $k_\phi$  coefficients and the  $\Gamma$  of the decays under consideration depends on  $k_{\phi\phi}^{Sym}$  and  $k_\phi$  which leads to tiny CPT asymmetry.

Now, for completeness, we start with the analysis of the  $\Gamma(H^+ \rightarrow W^+ H^0(h^0, A^0))$  in the model III without Lorentz violating effects.

Fig. 1 (2) is devoted to the  $m_{H^+}$  ( $\sin\alpha$ ) dependence of the  $\Gamma$  for  $H^0, h^0, A^0$  ( $H^0, h^0$ ) outputs and for  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ ,  $m_{A^0} = 200 \text{ GeV}$ ,  $\sin\alpha = 0.1$  ( $m_{H^+} = 400 \text{ GeV}$ ,  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ ,  $m_{A^0} = 200 \text{ GeV}$ ). In Fig. 1 solid (dashed, small dashed) line represents the dependence for  $H^0$  ( $h^0, A^0$ ) output. The  $\Gamma$  reaches 20 (10)  $\text{GeV}$  for  $h^0$  ( $A^0$ ) output, for the charged Higgs mass values  $\sim 400 \text{ GeV}$ . This is almost two order larger compared to the case where the output scalar is  $H^0$ . Notice that, here, we consider a weak mixing between neutral Higgs bosons and this results in a suppressed  $\Gamma$  for  $H^0$  output. Fig. 2 shows the effect of mixing of neutral Higgs scalars on the  $\Gamma$ s of  $H^+ \rightarrow W^+ H^0(h^0)$  decays.

The addition of Lorentz violating effects brings small contributions to the  $\Gamma$  and in the following we study the relative behaviors of the new coefficients driving the Lorentz violation.

In Fig. 3, we present the coefficient  $k_{\phi\phi}^{Sym} (Re[k_\phi^0])$  dependence of magnitude of the Lorentz violating part of the  $\Gamma$ ,  $\Gamma_{LV}$ , for  $H^0, h^0, A^0$  outputs and for the fixed values,  $m_{H^+} = 400 \text{ GeV}$ ,  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ ,  $m_{A^0} = 200 \text{ GeV}$ ,  $\sin\alpha = 0.1$ ,  $Re[k_\phi^0] = 10^{-20} \text{ GeV}$  ( $k_{\phi\phi}^{Sym} = 10^{-20}$ ). Here solid, dashed, small dashed inclined (almost straight) lines represent the dependence of  $\Gamma_{LV}$  to the coefficient  $k_{\phi\phi}^{Sym} (Re[k_\phi^0])$  for  $H^0, h^0, A^0$  outputs respectively. The  $\Gamma_{LV}$  is relatively more sensitive to the CPT even coefficient  $k_{\phi\phi}^{Sym}$  compared to the CPT odd one  $Re[k_\phi^0]$ . The  $\Gamma_{LV}$  lies in the range  $10^{-21} \text{ GeV} \leq \Gamma \leq 10^{-17} \text{ GeV}$  in the expected region of  $k_{\phi\phi}^{Sym}$ ,  $10^{-22} \leq k_{\phi\phi}^{Sym} \leq 10^{-18}$  for  $h^0$  output. For  $A^0$  output the upper and lower limits of the range for  $\Gamma_{LV}$  becomes almost half of the previous one. These limits are suppressed in the case of  $H^0$  output due to the weak mixing between neutral Higgs bosons. Increasing values of the CPT odd coefficient  $Re[k_\phi^0]$  causes slightly to decrease the  $\Gamma_{LV}$  for the fixed values of  $k_{\phi\phi}^{Sym}$ .

Fig. 4 (5) represents the  $m_{H^+}$  ( $\sin\alpha$ ) dependence of the  $\Gamma_{LV}$  for  $k_{\phi\phi}^{Sym} = 10^{-20}$ ,  $Re[k_\phi^0] = 10^{-20} \text{ GeV}$ ,  $H^0, h^0, A^0$  ( $H^0, h^0$ ) outputs and  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ ,  $m_{A^0} = 200 \text{ GeV}$ ,  $\sin\alpha = 0.1$  ( $m_{H^+} = 400 \text{ GeV}$ ,  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ ,  $m_{A^0} = 200 \text{ GeV}$ ). In Fig. 4 (5)

solid, dashed, small dashed (solid, dashed) lines represent the  $m_{H^+}$  ( $\sin \alpha$ ) dependence of the  $\Gamma_{LV}$  for  $H^0, h^0, A^0$  ( $H^0, h^0$ ) output. The  $\Gamma_{LV}$  reaches  $20(10)10^{-20} GeV$  for  $h^0$  ( $A^0$ ) output, for the charged Higgs mass values  $\sim 400 GeV$ . This is almost two order larger compared to the case where the output scalar is  $H^0$ , similar to the case where the SM decay width is considered. Fig. 5 shows the effect of mixing on the  $\Gamma_{LV}$  for neutral scalar outputs.

Finally we analyze the CPT violating asymmetry of the decays studied (see eq. (16)). This asymmetry is due to the existence of the CPT odd parameter  $k_\phi$  and it enters into the  $\Gamma$  as  $Re[k_\phi^0]$ .

Fig. 6 shows the  $Re[k_\phi^0]$  dependence of the  $A_{CPT}$  for  $k_{\phi\phi}^{Sym} = 10^{-20}$ ,  $m_{H^+} = 400 GeV$ ,  $m_{H^0} = 200 GeV$ ,  $m_{h^0} = 100 GeV$ ,  $m_{A^0} = 200 GeV$ ,  $\sin \alpha = 0.1$ . Here the  $A_{CPT}$  is the order of  $10^{-20}$  for all three different decays since the part without the Lorentz violating effects in the denominator highly suppresses the ratio and the behaviors of  $Re[k_\phi^0]$  for different outputs can not be distinguished.

At this stage we would like to summarize our results

- The Lorentz violation for the decays under consideration is regulated by CPT even  $k_{\phi\phi}^{Sym}$  and CPT odd  $k_\phi$  coefficients. The latter one is responsible for the tiny CPT asymmetry.
- The Lorentz violating part of the  $\Gamma$  is more sensitive to the CPT even coefficient  $k_{\phi\phi}^{Sym}$  compared to the CPT odd one  $Re[k_\phi^0]$  and it lies in the range  $10^{-21} GeV \leq \Gamma \leq 10^{-17} GeV$  for  $Re[k_\phi^0] = 10^{-20} GeV$ ,  $10^{-22} \leq k_{\phi\phi}^{Sym} \leq 10^{-18}$  in the case of  $h^0$  output.
- There exist a tiny  $A_{CPT}$  in the order of  $10^{-20}$  for all three different decays.

As a final result, the Lorentz violating effects for the charged Higgs decays under consideration are too small to be detected in the present experiments since they depend on the tiny coefficients which arise from a more fundamental theory at the Planck scale.

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## References

- [1] J. L. Diaz-Cruz, O. A. Sampayo, *Phys. Rev.* **D50**, 6820 (1994), J. Gunion, et.al., *Nucl. Phys.* **B294**, 621 (1987), M. A. Perez, A. Rosado, *Phys. Rev* **D30**, 228 (1984); Bisset



et.al., *Eur. Phys. J.* **C19**, 143 (2001), A. B. Bendezu, B. A. Kniehl, *Phys. Rev.* **D63**, 015009 (2001), Z. Fei et.al., *Phys. Rev* **D63**, 015002 (2001), D. J. Miller et. al., *Phys. Rev* **D61**, 055011 (2000); M. Carena, D. Garcia, *Nucl.Phys.* **B577** 88, (2000); T. Farris, H. E. Logan, *Phys.Rev.D* **69** 035005, (2004); P. Abreu et al., DELPHI Collaboration *Phys.Lett.* **B525** 17, (2002); OPAL Collaboration, G. Abbiendi et al., *Phys.Lett.* **B526** 221, (2002); J. Maalampi, N. Romanenko, *Phys.Lett.* **B532** 202, (2002); A. Belyaev, D. Garcia, J. Guasch, J. Sola, *JHEP* **0206** 059, (2002); H. J. He, S. Kanemura, C.P. Yuan, *Phys.Lett.* **89** 101803, (2002); K. A. Assamagan, Y. Coadou, A. Deandrea, *Eur.Phys.J.direct* **C4** 9, (2002); DELPHI Collaboration, G. Gomez-Ceballos for the collaboration, *Int.J.Mod.Phys* **A16** 839, (2001); S. Moretti, *Eur.Phys.J.direct* **C4** 15, (2002); S. Godfrey, P. Kalyniak, N. Romanenko, *Phys.Lett.* **B545** 361, (2002); ALEPH Collaboration, A. Heister et al., *Phys.Lett.* **B543** 1, (2002); S. Banerjee, M. Maity, *J.Phys.* **G28** 2443, (2002); S. Moretti, S. Kanemura, *Eur.Phys.J.* **C29** 19, (2003); Yi Jiang, Wen-Gan Ma, L. Han, Hong-Sheng Hou, *Commun.Theor.Phys.* **36** 61, (2001); A. Belyaev, D. Garcia, J. Guasch, J. Sola, *JHEP* **0206**, 059 (2002); M. Beccaria, F.M. Renard, S. Trimarchi, C. Verzegnassi, *Phys.Rev.* **D68** 035014, (2003); DELPHI Collaboration, J. Abdallah et al., *Phys.Lett.* **B552**, 127 (2003); S. Moretti, hep-ph/0306297; OPAL Collaboration, G. Abbiendi et al., *Phys.Lett.* **B577** 93, (2003); M. Muhlleitner, M. Spira *Phys.Rev.* **D68** 117701, (2003) S. Moretti, J. Rathsmann, *Eur.Phys.J.* **C33** 41, (2004); OPAL Collaboration, D. Horvath for the collaboration, *Nucl.Phys.* **A721** 453, (2003); Q. H. Cao, S. Kanemura, C.P. Yuan, *Phys.Rev.* **D69** 075008, (2004); O. Brein, T. Hahn, S. Heinemeyer, G. Weiglein, CERN-PH-TH-2004-021, IPPP-04-03, PITHA-04-03, DCPT-04-06, MPI-PHT-2004-18, Feb 2004. 4pp. Presented at SUSY 2003: SUSY in the Desert: 11th Annual International Conference on Supersymmetry and the Unification of Fundamental Interactions, Tucson, Arizona, 5-10 Jun 2003. hep-ph/0402053; DELPHI Collaboration, J. Abdallah for the collaboration, CERN-EP-2003-064, Apr 2004. 42pp., hep-ex/0404012; S.R. Slabospitsky, *Phys. Atom. Nucl.* **67**, 328 (2004).

- [2] L3 Collaboration, P. Achard et al., *Phys.Lett.* **B575** 208, (2003);
- [3] S. Andriga et.al., ALEPH, DELPHI, L3, OPAL Collaboration and the LEP working group for Higgs boson searches, (July, 200), <http://lephiggs.web.cern.ch/LEPHIGGS/papers>; P. Bock et.al., ALEPH, DELPHI, L3, OPAL Collaboration and the LEP working group for Higgs boson searches, CERN-EP-2000-055 (April, 2000); Abe et.al., CDF Collaboration, *Phys. Rev. Lett.* **79**, 357 (1997), B. Abbott et.al., D0 Collaboration, *Phys. Rev. Lett.* **82**, 4975 (1999).

- [4] DELPHI Collaboration, hep-ex/0404012.
- [5] E. Christove, H. Eberl, W. Majerotto, S. Kralm, hep-ph/0211063, (2002), T. Han, D. Marfatia, *Phys. Rev. Lett.* **86**, 1442 (2000)
- [6] V. Barger, R.J.N. Phillips and D.P. Roy, *Phys. Lett.* **B324**, 236 (1994), J. F. Gunion, S. Geer, hep-ph/9310333, J. F. Gunion, *Phys. Lett.* **B322**, 125 (1994), D. J. Miller, S. Moretti, D. P. Roy, W. J. Stirling, *Phys. Rev.* **D61**, 055011 (2000), S. Moretti, D. J. Roy, *Phys. Lett.* **B470**, 209 (1999), K. Odagiri, hep-ph/9901432, S. Raychaudhuri, D. P. Roy, *Phys. Rev.* **D53**, 4902 (1996).
- [7] M. Carena, D. Garcia, U. Nierste, C. E. M. Wagner, *Nucl. Phys.* **B577**, 88 (2000); M. J. Herrero, S. Penaranda, D. Temes, *Phys. Rev.* **D64** 115003, (2001).
- [8] R. Santos, A. Barosso, L. Brucher, *Phys. Lett.* **B391**, 429 (1997); S. Moretti, *Phys. Lett.* **B481**, 49 (2000); Y. S. Yang, C. S. Li, *Phys. Lett.* **B497**, 101 (2001).
- [9] J. L. Diaz-Cruz, M. A. Perez, *Phys. Rev.* **D33**, 273 (1986), J. Gunion, G. Kane, J. Wudka, *Nucl. Phys.* **B299**, 231 (1988), A. Mendez, A. Pomarol, *Nucl. Phys.* **B349**, 369 (1991), E. Barradas et.al., *Phys. Rev.* **D53**, 1678 (1996), M. C. Peyranere, H. E. Haber, P. Irulegui, *Phys. Rev.* **D44**, 191 (1991), S. Kanemura, *Phys. Rev.* **D61**, 095001 (2000).
- [10] Y. S. Yang and C. S. Li, *Phys. Lett.* **B497**, 101 (2001).
- [11] A. Akeroyd, A. Arhrib, E. M. Naimi *Eur.Phys. J* **C12** 451, (2000), A. Akeroyd, A. Arhrib, E. Naimi, *Eur.Phys. J* **C20** 51, (2001);
- [12] J. L. Diaz-Cruz, M. A. Perez, *Phys. Rev.* **D33**, 273 (1986), J. Gunion, G. Kane, J. Wudka, *Nucl. Phys.* **B299**, 231 (1988), A. Mendez, A. Pomarol, *Nucl. Phys.* **B349**, 369 (1991), E. Barradas et.al., *Phys. Rev.* **D53**, 1678 (1996), M. C. Peyranere, H. E. Haber, P. Irulegui, *Phys. Rev.* **D44**, 191 (1991), S. Kanemura, *Phys. Rev.* **D61**, 095001 (2000).
- [13] V. A. Kostelecky and S. Samuel, *Phys. Rev* **D39**, 683 (1989); *Phys. Rev* **D40**, 1886 (1989); *Phys. Rev. Lett.* **63**, 224 (1989); *Phys. Rev. Lett.* **66**, 1811 (1991); *Phys. Lett.* **B381**, 89 (1996); *Phys. Rev* **D63**, 046007 (2001); V. A. Kostelecky, M. Perry and R. Potting, *Phys. Rev. Lett.* **D84**, 4541 (2000).
- [14] S. M. Carroll, et. al, *Phys. Rev. Lett.* **D87**, 141601 (2001); Z. Guralnik, et. al. *Phys. Lett.* **B517**, 450 (2001); A. Anisimov et.al, *Phys. Rev* **D65**, 085032 (2002), C. E. Carlson,

- et.al., *Phys. Lett.* **B 518**, 201 (2001), I. Mocioiu, M. Pospelov, R.Roiban, *Phys. Lett.* **B489**, 390,2000, *Phys. Rev* **D65** 107702, (2002).
- [15] V. A. Kostelecky, ed. ,CPT and Lorentz Symmetry, World Scientific,Singapore,1999.
- [16] V. A. Kostelecky, R. Lehnert, and M. Perry, astro-ph/0212003.
- [17] D. Colladay and V. A. Kostelecky, *Phys. Rev* **D55**, 6760 (1997); **D58**, 116002 (1998); *Phys. Lett.* **B 511**, 209 (2001);
- [18] R. Lehnert and R. Potting, *Phys. Rev. Lett.* **93**, 110402, (2004); hep-ph/0408285
- [19] V. A. Kostelecky and R. Lehnert, *Phys. Rev.* **D 63**, 065008 (2002).
- [20] V. A. Kostelecky and A. Pickering, *Phys. Rev. Lett.* **91**, 031801 (2003); V. A. Kostelecky, C. D. Lane and A. G. M. Pickering, *Phys. Rev* **D65** 056006 (2002); Alexander A. Andrianov, P. Giacconi, R. Soldati, *JHEP* **0202** 030 (2002), H. Belich, M.M. Ferreira, J.A. Helayel-Neto, M.T.D. Orlando , *Phys. Rev* **D67**, 125011 (2003),H. Belich, J.L. Boldo, L.P. Colatto, J.A. Helayel-Neto, A.L.M.A. Nogueira, *Phys. Rev* **D68**, 065030 (2003); A.P. Baeta Scarpelli, H. Belich, J.L. Boldo, L.P. Colatto, J.A. Helayel-Neto, A.L.M.A. Nogueira, hep-th/0305089; D. Bazeia, T. Mariz, J.R. Nascimento, E. Passos, R.F. Ribeiro, *J.Phys.* **A36** 4937 (2003); M. S. Berger, *Phys. Rev* **D68**, 115005 (2003); D. Colladay, hep-ph/0301223; KTeV Collaboration, Y. B. Hsiung et.al., *Nucl. Phys. Proc. Suppl.* **86**, 312 (2000); Opal Collaboration, R. Ackerstaff et.al., *Z. Phys.* **C76**, 401 (1997); DELPHI Collaboration, M. Feint et. al., prep. DELPHI 97-98 CONF 80, (1997), BELLE Collaboration, K. Abe et. al., *Phys. Rev Lett.* **86**, 3228 (2001); V. A. Kostelecky, and R. Potting, *Phys. Rev.* **D51**, 3923 (1995); Colladay and V. A. Kostelecky, *Phys. Lett.* **B344**, 259 (1995); *Phys. Rev.* **D 52**, 6224 (1995); V. A. Kostelecky, and R. Van Kooten, *Phys. Rev.* **D54** 5585 (1996); V. A. Kostelecky, *Phys. Rev. Lett.* **80** 1818 (1998); *Phys. Rev.* **D61** 016002 (2000); **D64** 076001 (2001); N. Isgur et. al, *Phys. Lett.* **B515**, 333 (2001); O. Bertolami et.al, *Phys. Lett.* **B395**, 178 (1997); D. Bear et. al., *Phys. Rev. Lett.* **85**, 5038 (2000); D. F. Phillips et. al., *Phys. Rev.* **D63**, 111101 (2001); M. A. Humphrey et. al., physics/0103068; *Phys. Rev.* **A 62**, 063405 (2000); V. A. Kostelecky, and C. D. Lane, *Phys. Rev* **D60** 116010 (1999); *J. Math. Phys.* **40** 6245 (1999); R. Bluhm et.al., *Phys. Rev. Lett.* **88** 090801 (2002).H. Dehmelt et.al., *Phys. Rev. Lett.* **83**, 4694 (1999); R. Mittleman et.al., *Phys. Rev. Lett.* **83**, 2116 (1999); G. Gabrielse et.al., *Phys. Rev. Lett.* **82**, 3198 (1999); R. Bluhm et al., *Phys. Rev. Lett.* **82**, 2254 (1999); *Phys. Rev. Lett.* **79**, 1432 (1997); R. Bluhm and V. A. Kostelecky, *Phys. Lett.* **84**, 1381

- (2000); S. M. Carroll, G. B. Field and R. Jackiw, *Phys. Rev.* **D41**, 1231 (1990); V. A. Kostelecky and M. Mewes, *Phys. Rev. Lett.* **87**, 251304 (2001); V. W. Hughes et.al, *Phys. Rev. Lett.* **87**, 111804 (2001); R. Bluhm et.al., *Phys. Rev. Lett.* **84**, 1098 (2000); M. Mewes, hep-ph/0307161, R. Bluhm, V. A. Kostelecky, C. Lane, N. Russell, *Phys. Rev.* **D68**, 125008 (2003); R. Lehnert, *Phys. Rev.* **D68**, 085003 (2003).
- [21] R. Bluhm, V. A. Kostelecky and N. Russell, *Phys. Rev.* **D57**, 3932 (1998)
- [22] E. O. Iltan, *JHEP* **0306** 016 (2003); E. O. Iltan, hep-ph/0308151; E. O. Iltan, *Mod. Phys. Lett.* **A19**, 327 (2004).
- [23] D. L. Anderson, M. Sher, I. Turan, hep-ph/0403116.
- [24] J. Gunion, H. Haber, G. Kane and S. Dawson, The Higgs hunters guide (Addison-Wesley, New York, 1990).
- [25] D. Atwood, L. Reina, A. Soni, *Phys.Rev.* **D55**, (1997) 3156.

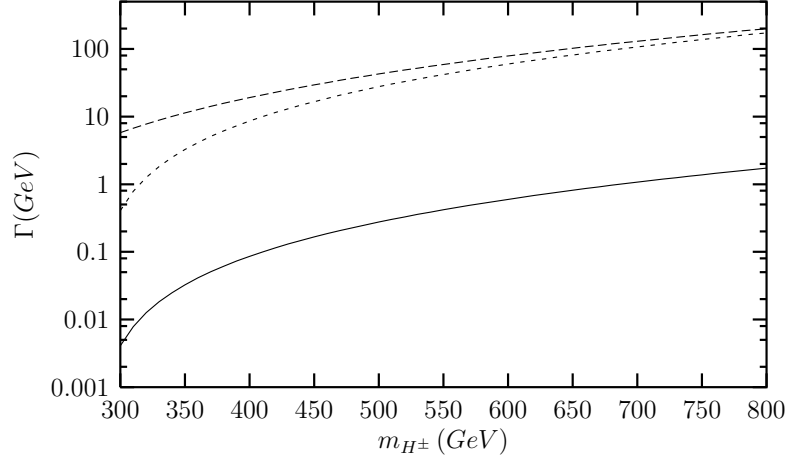


Figure 1: The  $m_{H^\pm}$  dependence of the  $\Gamma$  for  $H^\pm \rightarrow W^\pm H^0 (h^0, A^0)$  decay, for the fixed values  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ ,  $m_{A^0} = 200 \text{ GeV}$ ,  $\sin\alpha = 0.1$ . Here solid (dashed, small dashed) line represents the dependence for  $H^0 (h^0, A^0)$  output.

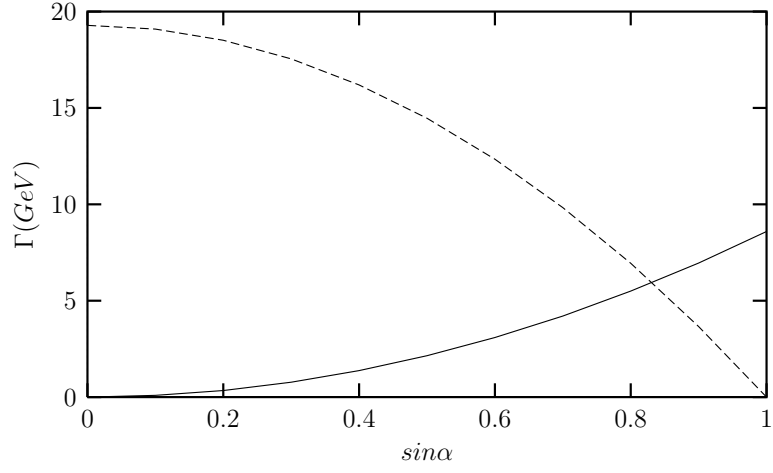


Figure 2: The  $\sin \alpha$  dependence of the  $\Gamma$  for  $H^+ \rightarrow W^+ H^0 (h^0)$  decay, for the fixed values  $m_{H^+} = 400 \text{ GeV}$ ,  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ . Here solid (dashed) line represents the dependence for  $H^0 (h^0)$  output.

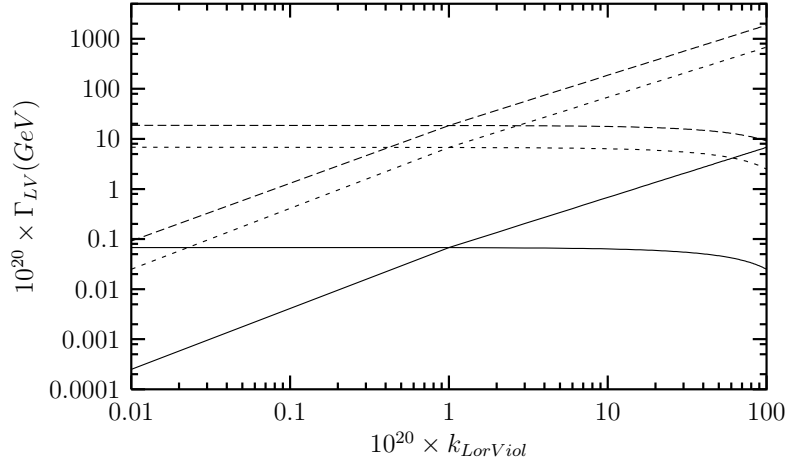


Figure 3: The coefficient  $k_{\phi\phi}^{Sym}(Re[k_\phi^0])$  dependence of the  $\Gamma_{LV}$  for  $H^+ \rightarrow W^+ S$ ,  $S = H^0, h^0, A^0$  decays for the fixed values  $m_{H^+} = 400 \text{ GeV}$ ,  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ ,  $m_{A^0} = 200 \text{ GeV}$ ,  $\sin\alpha = 0.1$  and for  $Re[k_\phi^0] = 10^{-20} \text{ GeV}$  ( $k_{\phi\phi}^{Sym} = 10^{-20}$ ). Here solid, dashed, small dashed inclined (almost straight) lines represent the dependence of  $\Gamma_{LV}$  to the coefficient  $k_{\phi\phi}^{Sym}(Re[k_\phi^0])$  for  $H^0, h^0, A^0$  outputs, respectively.

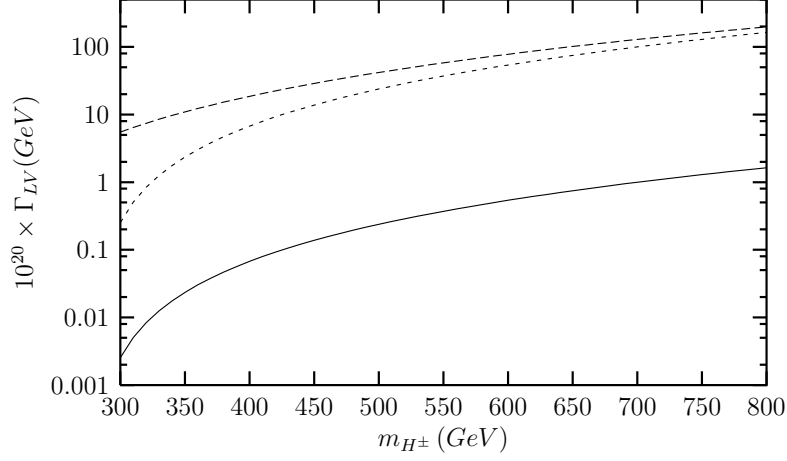


Figure 4: The Higgs mass  $m_{H^\pm}$  dependence of the  $\Gamma_{LV}$  for  $H^+ \rightarrow W^+ H^0 (h^0, A^0)$  decay, for  $k_{\phi\phi}^{Sym} = 10^{-20}$ ,  $Re[k_\phi^0] = 10^{-20}$ , and for  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ ,  $m_{A^0} = 200 \text{ GeV}$ ,  $\sin\alpha = 0.1$ . Here solid (dashed, small dashed) line represents the dependence for  $H^0 (h^0, A^0)$  output.

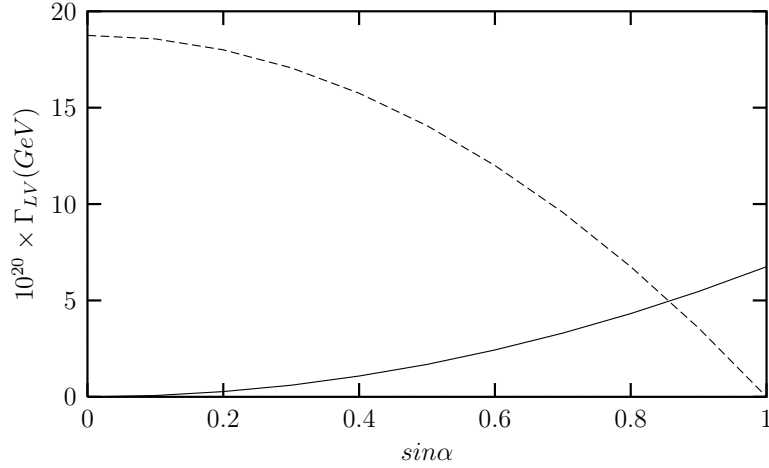


Figure 5: The  $\sin\alpha$  dependence of the  $\Gamma_{LV}$  for  $H^+ \rightarrow W^+ H^0 (h^0)$  decay, for  $k_{\phi\phi}^{Sym} = 10^{-20}$ ,  $Re[k_\phi^0] = 10^{-20} \text{ GeV}$  and for  $m_{H^\pm} = 400 \text{ GeV}$ ,  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ . Here solid (dashed) line represents the dependence for  $H^0 (h^0)$  output.



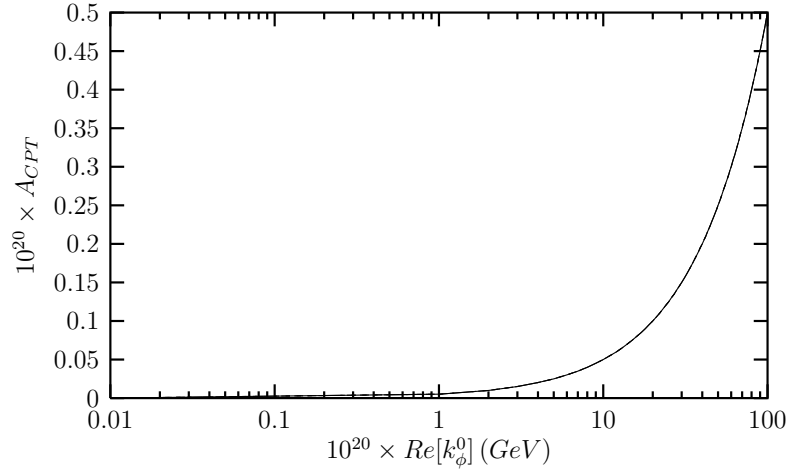


Figure 6:  $\text{Re}[k_\phi^0]$  dependence of the  $A_{CPT}$  for  $H^+ \rightarrow H^0 (h^0, A^0)$  decay, for  $k_{\phi\phi}^{Sym} = 10^{-20}$ ,  $m_{H^+} = 400 \text{ GeV}$ ,  $m_{H^0} = 200 \text{ GeV}$ ,  $m_{h^0} = 100 \text{ GeV}$ ,  $m_{A^0} = 200 \text{ GeV}$ ,  $\sin\alpha = 0.1$ .